WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA

GOODWIN J. KNIGHT, Governor

INVESTIGATION OF THE SACRAMENTO-SAN JOAQUIN DELTA

Report No. 1

GROUND WATER GEOLOGY

MAY 1956

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INVESTIGATION
OF THE
SACRAMENTO-SAN JOAQUIN DELTA

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GROUND WATER GEOLOGY

* * *

INTRODUCTION

This series of five reports is designed to furnish new and additional factual data collected during the past three years, with analyses thereof, that are germane to those hydrologic problems in the State's water development programs which call for the use of Delta channels as conveyance conduits and as sources of diversion.

The Sacramento-San Joaquin Delta lies in the Central Valley of California and embraces the confluent channels and tributaries of the Sacramento River which flow into it from the north and of the San Joaquin River which flow into it from the south. The Delta is virtually a solid block of nearly 400,000 acres of irrigated agricultural land interlaced by more than 600 miles of tidal channels which in turn surround more than 50 islands lying at or below sea level and which are protected by levees.

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The strategic geographic location of this Delta makes it the pivotal conveyance link across which the abundantly surplus water supplies of the northern portion of the State are transported to the water-deficient areas of the southern portion of the State to permit the continued agricultural, industrial and municipal growth of those areas. The Central Valley Project has been designed, constructed and put into operation to take advantage of the Delta channels to convey some 5000 second-feet of the surplus Sacramento Valley waters to the south into the San Joaquin Valley. The plans of the Feather River Project call for the transfer and conveyance of an additional 11,000 second-feet through these same tidal Delta channels.

Despite the recognized importance of the pivotal position the Delta plays, or will play, in major programs of water development in California there has been a dearth of geologic, hydraulic, hydrologic, and salinic information of the physical phenomena present. Such information is essential for intelligent planning of water transfer through this Delta area. Furthermore, the fruition of major conservation and transportation plans may give rise to certain ill effects upon the agricultural enterprises within the Delta area.

An investigation so comprehensive as to cover and report upon all of the facets of pertinent knowledge concerning the Delta area would be prohibitive in cost at this time. This series of reports perforce is limited to some of these facets, namely,

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ground water geology, water source and water utilization phenomena on two of the Delta islands, quantities and qualities of applied water and of drainage water in the Delta, and the extent of sea-water intrusion in Delta channels.

This report is the first in this series and deals with some of the geologic and salinic aspects of the ground waters present in the Delta.

Prior Investigations and Reports

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Scope of This Report

The geologic investigation in the Sacramento-San Joaquin Delta area was limited primarily to the determination of those features in the region which affect ground water occurrence, movement, and quality. This report presents the results of a study of the location, extent, physical character, structure and continuity of the various deposits which comprise the water-bearing series in the area.

The location of the area of investigation and the surface distribution of the geologic units in the Delta Area are shown on Plate 1. The subsurface characteristics of the units are shown on Plates 2 and 3. The thickness of peat and related organic sediments is shown on Plate 4. Contour lines of equal elevation of the interface between upper fresh ground water and lower saline ground water (i.e., base of fresh water) are shown on Plate 5. The stratigraphy, physical character, and water-bearing properties of all deposits in the area are summarized in Table 1. Mineral analyses of surface and ground water in the area are tabulated in Table 2 and are graphically presented in Plates 6 and 7.

GEOLOGIC FORMATIONS

Geologic formations underlying the Sacramento-San Joaquin Delta area include deposits which range in age from pre-Cretaceous to Recent (Table 1). A basement complex of pre-Cretaceous igneous and metamorphic rocks underlies all of the Delta area at an unknown depth. Sedimentary rocks overlying this basement complex are of marine and continental origin and include undifferentiated Eocene and Cretaceous marine sediments. Overlying these consolidated sediments are the Valley Springs and Mehrten formations on the east and the San Pablo Group on the west, which are of marine and continental origin and are Miocene in age. These units in turn are overlain by continental late Tertiary-Quaternary formations, consisting of the Tulare on the west and south, the Laguna on the east, and the Montezuma and Tehama on the north. Unconsolidated Quaternary sediments including older alluvium, the Victor formation, and the west side alluvial fans, all of Pleistocene age, and the Delta deposits of Recent age constitute the uppermost horizon of sediments in the Delta (Plate 2).

In relation to the occurrence of ground water and to water-bearing characteristics, the lithologic units can be divided into two groups. The first group consists of deposits of major importance as a source of ground water such as the Sacramento-San Joaquin Delta deposits of post-Mehrten to Recent age; the unconsolidated Victor formation and related continental sediments of Recent and Pleistocene age in the eastern portion of the area;

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the west side alluvial fan deposits and west side older alluvial deposits, all of Pleistocene age; the Laguna and Tulare formations of Plio-Pleistocene age; and the semi-consolidated Mehrten formation of Miocene age. The second group consists of deposits of minor importance as a source of ground water such as the consolidated pre-Cretaceous basement complex; the undifferentiated Cretaceous and Eocene sediments; and the Valley Springs and San Pablo Group of Miocene age. The units in this second group are designated as the nonwater-bearing series and will be only briefly described in this report.

Water-Bearing Series

Ground water beneath the Sacramento-San Joaquin Delta is not stored in one single mass of homogeneous sediments, but rather in distinct sand and gravel layers in the Quaternary and late Tertiary deposits. The principal lithologic unit in which ground water occurs is the Sacramento-San Joaquin Delta deposits. These water-bearing deposits constitute a thick section of sediments which thin out to the east and west on the valley floor surrounding the Delta Lowlands (Plate 3). They are thickest along the central part of the Delta, being in excess of 2,500 feet.

Sacramento-San Joaquin Delta Deposits. This unit, identified on Plate 1 by the symbol (Qrb), includes all of the fine-grained deposits in the Delta area of post-Mehrten age.

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They are contemporaneous with the Victor formation and related continental sediments, with the Arroyo Seco gravel-Laguna formation which occurs east of the Stockton area, probably the older alluvium, the Montezuma formation and the continental sediments to the north, south and west of the Delta (3, 16). Total thickness of this unit may exceed 2,500 feet in the central portion of the Delta.

The upper portion of these Delta deposits comprises Recent stream channel and some flood basin deposits. The stream channel deposits comprise silt, sand and gravel laid down in stream channels of the Sacramento and San Joaquin Rivers during times of decreasing flood flows. The flood basin deposits consist of clays, silts, sands and some organic material which have a low permeability (Plate 3). Deposition of this material took place in overflow basins during flood stage periods. The Sacramento-San Joaquin Delta deposits contain a network of low ridges along major streams which are largely fine grained mineral deposits laid down (prior to levee construction) during periods of high water.

In the downstream Delta areas and along minor sloughs, sediments are found which are largely organic but deposits of peat and organic clays are found throughout the entire Delta area, except in the permanent channels of the older streams (Plate 4). In these channels, river sand has been deposited in lieu of peat. Most of the downstream Delta islands show deposits

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of peat at their centers, 20 or more feet in thickness, and thinner deposits along their peripheries. In a few isolated locations on islands near the outlet of the Delta, peat with more than 40 feet of thickness has been logged in test holes. On some of the islands along the Sacramento River, river sand up to 5 feet in thickness has been deposited over the peat. The organic matter has a low permeability, and the moisture content of this material is very high, ranging from about 100 to over 500 per cent of the dry weight.

Older fine-grained Delta deposits which underlie the thin layer of Recent stream channel and flood basin deposits are of considerable thickness and merge with the coarser alluvial deposits of the Victor formation and the Arroyo Seco gravel-Laguna formation which lie to the east of Stockton. They are predominately silt and clay with interbedded sand and gravel bodies. Ground water in these Delta deposits occurs in the relatively discontinuous sand and gravel bodies within the predominately fine-grained deposits. Wells located in this material usually yield only moderate quantities of water with large drawdowns. Saline waters are found throughout all depths in these deposits except for thin lenses of fresh water which occasionally are found overlying the saline waters.

The line on Plate 1 showing the surface contact between the Victor formation and the Delta deposits is intended to be a generalized location of the contact at depth. This contact

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between the Delta deposits and the coarser alluvial deposits from the east is interfingered due to alternating transgressive deposition of the two units. Considerable hydrologic significance is attached to this contact in that it results in a break in hydraulic continuity between the two deposits.

Victor Formation and West Side Alluvial Fans. These sediments identified on Plate 1 by the symbol (Qal) are contemporaneous in part with the Delta deposits and were deposited on floodplains and alluvial fans. They entirely flank the Sacramento-San Joaquin Delta. These deposits are composed of poorly sorted sand, gravel, silt and clay, and are low to moderate in permeability. (3, 16). Sand and gravel stringers of high permeability are extensive, and represent deposits of coarse sediments in active stream channels. In general, the floodplain and fan deposits become finer the farther they become removed from their source in the mountainous areas surrounding the Delta.

Ground water in these formations is generally unconfined. In general the yield to wells in these formations is moderate. However, where wells penetrate the coarse permeable buried channels the yield may be relatively high.

Older Alluvium. These slightly compacted alluvial deposits are identified on Plate 1 by the symbol (Qoal). They outcrop in the area north of the Montezuma Hills. These deposits are composed of an upper fine-grained phase which is low in permeability and a basal coarse-grained member of sand and gravel which

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supplies appreciable quantities of ground water in the Putah Creek area (7).

Tertiary-Quaternary Deposits. These slightly compacted alluvial deposits are identified on Plate 1 by the symbol (TQc). These sediments include: the Montezuma formation exposed in the Montezuma Hills north and west of the Delta; the Tehama formation which underlies the alluvium in the northwestern portion of the Delta; the Tulare formation which underlies the more recent deposits in the southwestern portion of the Delta; and the Laguna formation and related eastside deposits which underlie the Recent alluvium and Victor formation in the eastern part of the area.

The Montezuma formation is exposed in the Montezuma Hills north and west of the Delta in the vicinity of the confluence of the Sacramento and San Joaquin Rivers and underlies the portions of the northern Delta area at shallow depths. This deposit represents the remnants of extensive alluvial-fan, flood-plain and terrace deposits of Plio-Pleistocene age. The formation consists of horizontally bedded slightly consolidated clays, silts, sands and gravels all more or less lenticular in character (33). Ground water extractions from this unit are small due to the low permeability of the formation.

The Tehama formation, exposed in the area north of the Montezuma Hills, is a heterogeneous unit composed of slightly to moderately compacted sandy silt, silt, clay and fine sand, with lenticular bodies of sand, gravel, clay and gravel (7). Pumiceous tuff, conglomerate and slightly cemented sand and gravel are

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widespread in the basal portion of the unit. These fresh-water-bearing sediments extend to depths of approximately 3,000 feet in Putah Creek area. Permeability is low with respect to the overlying alluvium and coarse stream-channel deposits, resulting in greatly reduced specific capacity in wells.

The Tulare formation is found on the southwestern side of the Delta area, underlying the west side alluvial fan deposits. It is contemporaneous in part with the older alluvial deposits and the east side Laguna formation. The Tulare formation is composed mainly of a massive, friable, fine-grained silty sandstone (18). This sandstone grades erratically in short distances to sandy, soft claystone. These sediments represent flood-plain and alluvial-fan deposits of late Tertiary-Quaternary age. The "Corcoran Clay", originally named by Frink and Kues (14), is a Pleistocene lacustrine deposit of pumiceous nature within the Tulare formation. This clay which acts as a confining impermeable body to the downward movement of ground water, has been traced northward from the southern San Joaquin Valley to the vicinity of Tracy. At this point the "Corcoran Clay" is identified at depths of more than 200 feet below land surface. There is insufficient well-log and electric-log control to trace this unit into the Delta north of Tracy.

The Laguna formation and related eastside deposits are found on the eastern side of the Delta area immediately underlying the Victor formation. These deposits outcrop in the foothills east of Stockton. The Laguna formation, which is composed largely

of sands, silts and clays, with small discontinuous lenses of gravel, varies markedly in physical character both vertically and laterally. As differentiated in well logs, the brown, pink and occasional blue clays and the yellow, brown and red sands are the outstanding characteristics of the Laguna formation. Sediments of this group are relatively coarse in the eastern part of the area and become finer toward the Delta region.

Mehrten Formation. The Mehrten formation consists of siltstone, sandstone, and conglomerate with discontinuous lenses of sand and clay, and of volcanic agglomerate derived from mud flows. Dark, relatively permeable sandstone members of this formation, locally known as the "black sands", are the most characteristic material noted in well logs. The black color, actually blue to dark gray when dry, is due to the opaline coating of the andesitic sandstones. The white-to-gray colored clay and silt members are extensive in the upper portion of the formation. Conglomerates in the formation are poorly sorted and well cemented, hence have a low permeability (16).

The Mehrten formation in the outcrop area along the flank of the Sierra Nevada has a general westerly dip of approximately 100 feet per mile. Beneath the Stockton area, where the formation attains a thickness of approximately 400 feet, its top is approximately 1,200 feet below sea level. Its top elevation beneath the central portion of the Delta is unknown.

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Ground water in this formation is largely confined by the lenses of relatively impermeable clays and silts. Saline water and gas occur in the deposits beneath the Stockton area and in the Delta area to the west. However, in the area to the east of Stockton, the Mehrten formation yields fresh water to deep irrigation wells.

Nonwater-Bearing Series

The nonwater-bearing series do not absorb, transmit or yield water readily and include the pre-Cretaceous igneous and metamorphic rocks; undifferentiated Cretaceous and Eocene sediments, the Chico, Panoche and Moreno formations of Cretaceous age; the Markley formation of Eocene age, and the consolidated Valley Springs and San Pablo Group of Miocene age. They occur at considerable depth below the Delta area and contain brackish or saline water.

GEOLOGIC CONDITIONS PERTAINING TO THE OCCURRENCE, MOVEMENT AND QUALITY OF GROUND WATER

Geologic features greatly influence the occurrence, movement, and quality of ground water in the Sacramento-San Joaquin Delta Area. In a large portion of the Delta it is difficult to obtain sufficient water of a quality suitable for domestic and irrigation purposes. However, sufficient quantities of good quality ground water are generally obtained throughout the valley floor area surrounding the Delta.

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Occurrence

Ground waters beneath the area of investigation are stored in the finer grained Delta deposits of Recent to post-Mehrten age, and in the surrounding coarse alluvial deposits. Ground waters in the Delta deposits occur in a series of poorly connected sand and gravel lenses which locally are confined by silts and clays, giving rise to local pressure effects. The large percentage of fine-grained materials and the lenticular nature of the deposits cause the permeability of the sediments to be low.

The coarse, moderately to highly permeable alluvial deposits, which occur in the valley floor areas surrounding the Delta, contain large quantities of fresh water which are largely unconfined. The permeability of these sediments varies greatly; however, they are generally moderately permeable.

Movement

Data showing free water-table slopes and piezometric gradients, obtained during recent ground-water studies covering not only the Delta area but also the valley floor areas surrounding the Delta, indicate a general ground-water movement toward the Delta from the valley-floor sediments on the north, east and south. This movement, however, is intercepted and ground-water elevations are depressed along much of the perimeter of the Delta where heavy pumping extractions are presently practiced. Ground-water movement outward from the Delta may occur near such ground-water depressions. This outward movement from the Delta is

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probably supported largely by the continuous presence of surface water supplies in the interlacing, tide-water channels of the Delta and in part by the rising water from deeper seated sources in the central portion of the Delta. On the other hand, in certain sectors of the perimeter ground-water gradients toward the center of the Delta still prevail and some ground-water movement toward the Delta must therefore occur. Although underflow to the Delta from deep-seated sources is not significant in quantity, ground-water accretions to the Delta in the form of return flows from irrigation water applied to the Delta Uplands are significant. The specific sectors where there presently exists accretions to the Delta lie north of the Montezuma Hills, west of Lodi, south of Stockton and northwest of Tracy through Contra Costa County (9). Under present conditions of heavy extractions of ground water outside of the perimeter of the Delta the ground-water outflows are apparently not appreciable and appear to be nearly equal to the accretions, as evidenced by the results of the special lunar-cycle measurement of Delta outflow made by the Water Project Authority in September 1954.

There is no evidence of any geologic structures extending upward into the water-bearing deposits in the central portion of the Delta which would obstruct the lateral movement of fresh ground water. However, hydrologic and water quality data indicate that an impediment to the lateral movement of ground water exists in the eastern edge of the area near Stockton (3). This discontinuity is believed to be due to a depositional contact

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between the coarser alluvial deposits east of Stockton and the finer-grained Delta deposits west of Stockton. There is an abrupt change in permeability across this contact zone, from the permeable upland strata to the relatively impermeable Delta deposits. A hydraulic gradient of approximately 45 feet per mile existed across this zone in the spring of 1953. In addition, a marked change in the mineral characteristics of ground water in the Quaternary sediments exists across this zone. A fresh-saline water interface approximates the boundary of this zone. The contact zone is known to extend for a considerable distance north and south of the Stockton area; however, data concerning its total extent and its effectiveness in these areas is not yet available.

The vertical movement of ground water is impeded locally throughout the Delta by numerous silt and clay horizons. There is insufficient well-log information available to determine the location, extent, and physical characteristics of these confining members.

Quality

Ground waters in the area investigated are of two general types, predominately sodium-chloride water found in the Delta area and a calcium-magnesium or sodium-bicarbonate water found generally throughout the areas surrounding the Delta.

Plates 6 and 7 are graphical representations of the various waters in and surrounding the Delta. The mineral constituents in equivalents per million are plotted to indicate the

concentrations of the various waters. The plates manifest the definite similarity of the brackish-to-saline connate waters found at various depths throughout the area studied.

Ground waters in the areas surrounding the Delta are generally of excellent quality with low mineral content. The waters vary in character from a calcium-magnesium-bicarbonate water to a sodium-bicarbonate water with moderately low total solids (Table 2 and Plates 6 and 7). However, at depths greater than that penetrated by most wells, a highly saline water is encountered (Plate 5).

In the central portion of the Delta there are approximately 200 square miles of land underlain by poor quality ground water at depths less than 100 feet from the surface (Plate 5). This water is a saline connate water which generally contains high percentages of sodium and chloride ions and relatively low concentrations of calcium and sulphate ions (Plate 6). Chloride content of the water at the interface contoured on Plate 5 varies between about 350 ppm and 1000 ppm. It is this area from which rising waters of poor quality can gain access to surface waters in the Delta. It has been estimated from studies by the Division of Water Resources, Water Quality Branch, that over 20,000 acre-feet, or an average of 28 second-feet of saline connate waters rise to the surface each year.

In the cation triangle, Plate 7, it may be noted that there are two major groupings. The first group consists of the

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fresh waters found in the areas surrounding the Delta and the shallow fresh-water lenses in the Delta area which are floating on the more dense brackish water. The second grouping represents the brackish-to-highly-saline waters found at shallow depths in the Delta area and underlying the surrounding areas at greater depths.

The anion triangle depicts a rather broad scattering with only a single grouping of the waters containing high concentration of chloride ions.

CONCLUSIONS

1. Ground water beneath the Sacramento-San Joaquin Delta occurs in a thick section of relatively fine-grained unconsolidated Quaternary and late Tertiary deposits.

2. Ground water adjacent to the Delta occurs in relatively coarse-grained alluvium, Victor formation and west side alluvial fans of Quaternary age, and in the Montezuma, Tehama, Tulare and Laguna formations of Quaternary and late Tertiary age.

3. There are no known structural barriers to the lateral movement of ground water within the Delta. However, silt and clay lenses of unknown thickness and extent locally impede the vertical movement of ground water.

4. A depositional contact zone between the coarser sediments to the east and the finer Delta sediments to the west occurs along the eastern border of the Delta in the vicinity of

Stockton. This zone appears to impede and prohibit eastern movement of poor quality sodium-chloride water into the excellent quality ground water underlying the Stockton area.

5. Ground waters in and adjacent to the Delta are of two general types, a predominately sodium-chloride type water which occurs in the central portion of the Delta, and an excellent calcium-magnesium or sodium-bicarbonate type water which occurs generally throughout the areas surrounding the Delta.

6. Rising saline waters unsuitable for most beneficial uses occur at shallow depth over 200 square miles in the central portion of the Sacramento-San Joaquin Delta.

7. Appreciable quantities of fresh ground water of a mineral quality suitable for most beneficial uses occur in unconsolidated sediments in the periphery of and immediately adjacent to the Delta.

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TABLE 1

GEOLOGIC FORMATIONS, SACRAMENTO-SAN JOAQUIN DELTA

	Geologic Age	Formation and Symbol on Plate 3	Approximate Thickness (feet)	Physical Character	Water-Bearing Properties
QUATERNARY	Recent	Sacramento-San Joaquin Delta Deposits. Qrb	100	Predominately impervious clays and silts, with some sand. Becomes highly organic in central delta area.	This material is low in permeability. Brackish and saline waters are extensive in areal extent in the central portion of the Delta.
	Pleistocene	Victor Formation and Related Continental Sediments. Qal	150	Unconsolidated gravel, sand, silt and clay deposits with extensive sand and gravel stringers.	This material is moderately permeable and yields fresh water.
		Arroyo Seco Gravel and Unnamed Pleistocene Gravels. Qrb	150	Sand, gravel, silt and clay.	This material varies markedly in permeability. However, in general it is moderately permeable and yields fresh water.
		Older Alluvium Qoal	Unknown	Sand, gravel, silt and clay.	Basal portion in Putah Creek area is permeable and yields large quanties of water. Upper fine-grained deposits are low in permeability.
	Pliocene	Montezuma Formation, Tehama Formation, Laguna Formation, Tulare Formation. TQc	500-1000	Poorly sorted sand, gravel, silt and clay.	This material is moderately permeable and yields fresh water.
TERTIARY	Miocene	Mehrten Formation	400	Conglomerate, silt and clay with interbedded lenses of black sands and agglomeratic material derived from andesitic mudflows.	The conglomerate, silt and agglomeratic material is relatively impermeable, the black sands are highly permeable and yield saline water in the Stockton area and fresh water to the east.
		Valley Springs Formation	500	Consolidated rhyolitic tuffs, conglomerates, clay-shales, and sandstones.	This material is only slightly permeable and contains saline water in the Stockton area and fresh water to the east.
		San Pablo Group	1000	Interbedded massive sandstones and shale of continental and marine origin. Contemporaneous in part with the Mehrten and Valley Springs formations.	Nonwater-bearing except along fractures and joints
	Eocene	Markley Formation and Undifferentiated Lower Eocene Formations	Unknown	Marine sands and shales.	Nonwater-bearing except along fractures and joints.
CRETACEOUS		Moreno Formation Panoche Formation Chico Formation	Unknown	Marine sands and shales.	Nonwater-bearing except along fractures and joints.
PRE-CRETACEOUS		Pre-Cretaceous Consolidated Rock	Unknown	Igneous and metamorphic rocks	Nonwater-bearing except along fractures and joints.

Sacramento - San Joaquin Delta Deposits Qrb

The delta deposits comprise impervious clays and silts, with some sand and gravel.

The delta deposits have a low permeability due to poor sorting and a large percentage of fines. Brackish to saline waters are generally found in wells to all depths.

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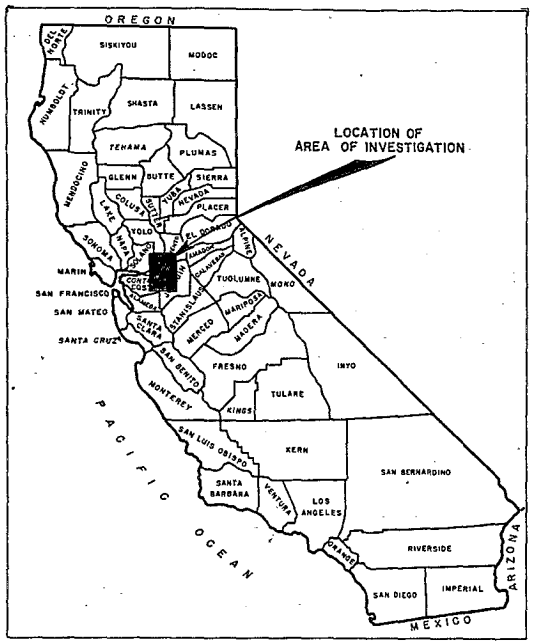
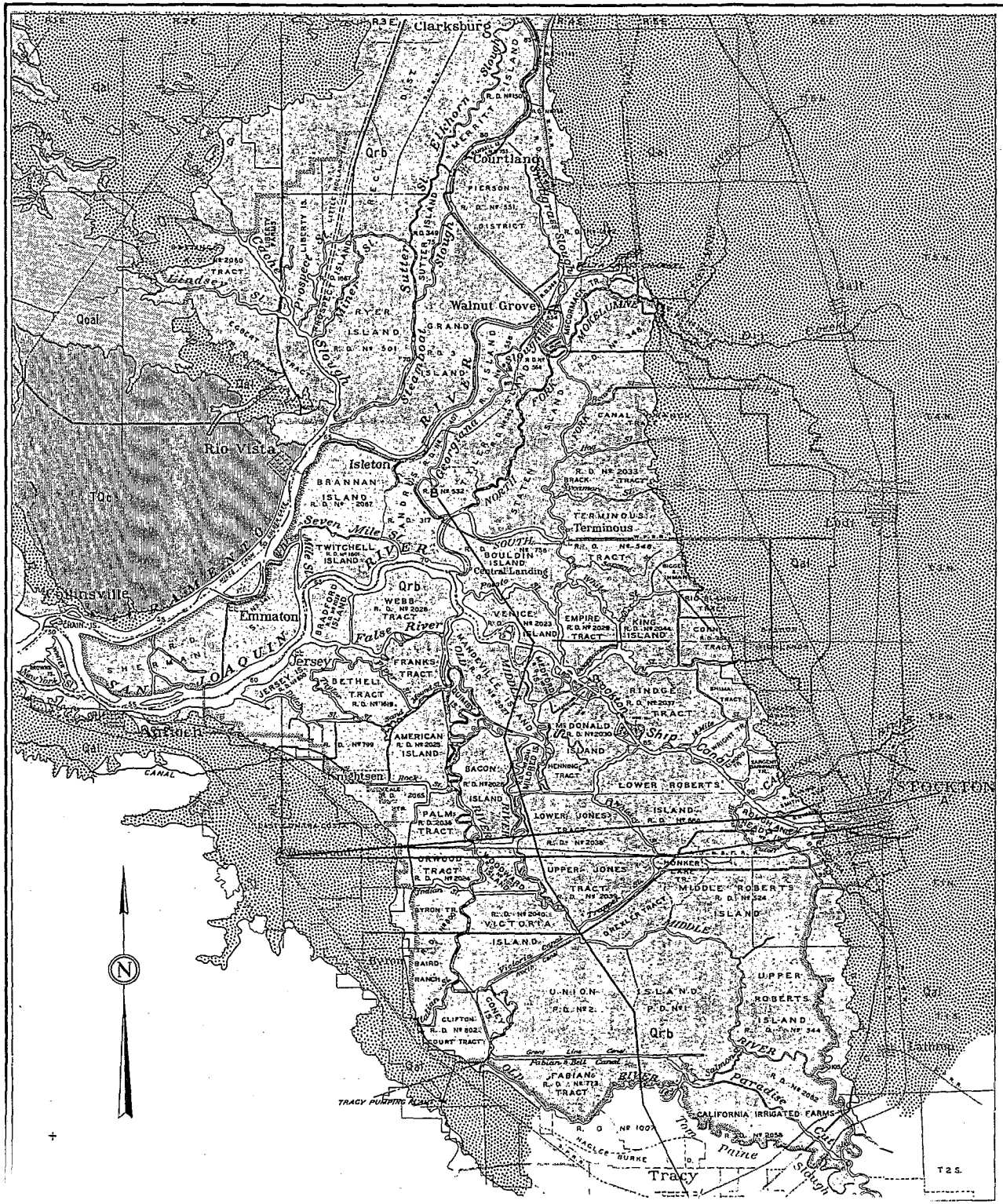
TABLE 2

MINERAL ANALYSES OF SELECTED GROUND AND SURFACE WATERS

Mineral constituents in parts per million / equivalents per million

No.	Source	Stream Sampling or Well Number M.D.B.&M.	Date sampled	Temp. °F	Specific conductance (micromhos at 25°C)	pH	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Boron (B)	Silica (SiO_2)	Total[a] dissolved solids ppm	Per cent sodium	Hardness as $CaCO_3$ Total ppm	Hardness as $CaCO_3$ N.C. ppm	Depth in Feet	Remarks
1	Ocean Water off Point Cabrillo	—	9-15-53	—	48,200	7.6	387 19.31	1260 103.62	10400 452.23	391 10.0	0.0 0.0	135 2.2	2660 55.38	18800 530.2	9.8 0.16	---	3.9	0.4	34000	7.7	6150	6040	—	
2	San Joaquin River, IN/6E-16 at Garwood Bridge	101	5-13-53	—	303	7.4	18 0.90	6.8 0.56	32 1.39	2 0.05	0.0 0.0	72 1.18	18 0.38	46 1.30	1.1 0.02	---	0.02	15	174	48	73	14	—	
3	San Joaquin River, IN/6E-16 at Garwood Bridge	101	9-17-53	77	323	—	18 0.90	11 0.90	29 1.26	1.3 0.046	0.0 0.0	94 1.54	26 0.54	38 1.07	0.4 0.006	---	0.11	16	187	41	90	13	—	
4	Eastern edge of Delta area; gas well at Stockton	IN/6E-23B1	9-2-52	88	12300	6.8	8.55 42.66	173 14.23	1540 66.97	115 2.94	0.0 0.0	44 0.72	0.7 0.01	4360 122.99	0.5 0.0	---	0.91	83	7150	53	2810	—	2000	
5	Well in Stockton area	IN/6E-2G2	2-16-53	—	365	8.0	4.6 0.23	2.6 0.21	75 3.26	0.9 0.02	0.0 0.0	154 2.52	1.1 0.02	41 1.16	0.6 0.01	---	0.37	62	264	87	22	0	1000	Well located east of Delta area
6	Well in Stockton area	IN/7E-7E1	8-12-52	73	274	7.9	21 1.05	7.7 0.63	27 1.17	2.7 0.07	0.0 0.0	138 2.26	5.7 0.12	15 0.42	1.5 0.02	---	0.26	58	207	40	84	0	250	Same
7	Area west of Delta in foothills of Coast Range	IS/3E-15F	1911	120	—	—	701 34.97	101 8.96	3886 169.0	33 0.85	72 2.4	— —	1.0 0.02	7527 212.0	0.0 0.0	---	16	30	--	--	--	---	10	Same
8	Area south of Delta, near Tracy	2S/5E-17Q1	6-30-54	63	804	7.4	52 2.59	18 1.45	92 4.00	2.6 0.07	0.0 0.0	194 3.18	135 2.81	70 1.97	9.9 0.16	---	0.90	29	505	49	202	43	620	Well located south of Delta area
9	Area south of Delta, near Tracy	3S/5E-6A	7-20-53	68	841	7.5	63 3.14	18 1.48	84 3.65	4.2 0.11	0.0 0.0	186 3.05	111 2.31	80 2.26	--- ---	---	0.50	--	546	44	231	78	170	Well located south of Delta area
10	Area northwest of Rio Vista	6N/1E-10H1	8-12-52	66	714	8.1	41 2.05	43 3.54	49 2.13	0.3 0.01	0.0 0.0	320 5.24	24 0.50	36 1.02	59 0.95	---	0.20	40	450	28	280	18	150	Well located north of Delta area
11	Area northwest of Rio Vista	5N/2E-27K1	8-12-54	68	1120	8.9	16 0.80	31 2.52	214 9.31	1.6 0.04	41 1.37	432 7.08	114 2.37	55 1.55	0.1 0.00	---	1.5	38	726	73	166	0	55	Well located north of Delta area
12	Shallow well in Delta west of Stockton	IN/5E-21K1	7-7-54	61	992	8.3	57 2.84	24 1.97	115 5.00	4.0 0.10	2 0.07	109 1.79	108 2.25	201 5.67	3.3 0.05	---	0.17	37	605	50	240	148	40	Well located in eastern Delta
13	Water well in Delta area	3N/4E-36R1	7-29-54	61	7460	7.1	450 22.46	146 11.92	780 33.92	5 0.13	0.0 0.0	114 1.87	3.2 0.07	2380 67.12	0.5 0.01	---	0.19	38	3860	50	1720	1630	100±	Flowing well on Empire Island
14	Gas well in Delta area	3N/3E-17	5-16-55	—	28,600	6.8	2.39 11.93	59 4.86	6830 297.00	79 2.02	0.0 0.0	315 5.16	30 0.62	10,800 304.59	0.9 0.01	---	146	43	18,400	94	839	581	5400	Gas field brine, Twitchell Island
15	Gas well in northern part of Delta area	5N/5E-26	---	--	17,800	7.7	354 17.66	146 11.97	3540 153.93	40 1.02	0.0 0.0	171 2.80	20 0.42	6340 178.81	1.6 0.03	---	3.9	18	10,600	83	1480	1340	3300	Gas field brine, Thornton gas field





LEGEND

- Qrb — SACRAMENTO–SAN JOAQUIN DELTA DEPOSITS
- Qal — ALLUVIUM AND VICTOR FORMATION
- Qoal — OLDER ALLUVIUM
- TQo — TERTIARY–QUATERNARY SEDIMENTS
- UNDIFFERENTIATED NONWATER–BEARING TERTIARY AND CRETACEOUS SEDIMENTS
- GEOLOGIC CONTACT
- A–A′ GEOLOGIC SECTION LINE

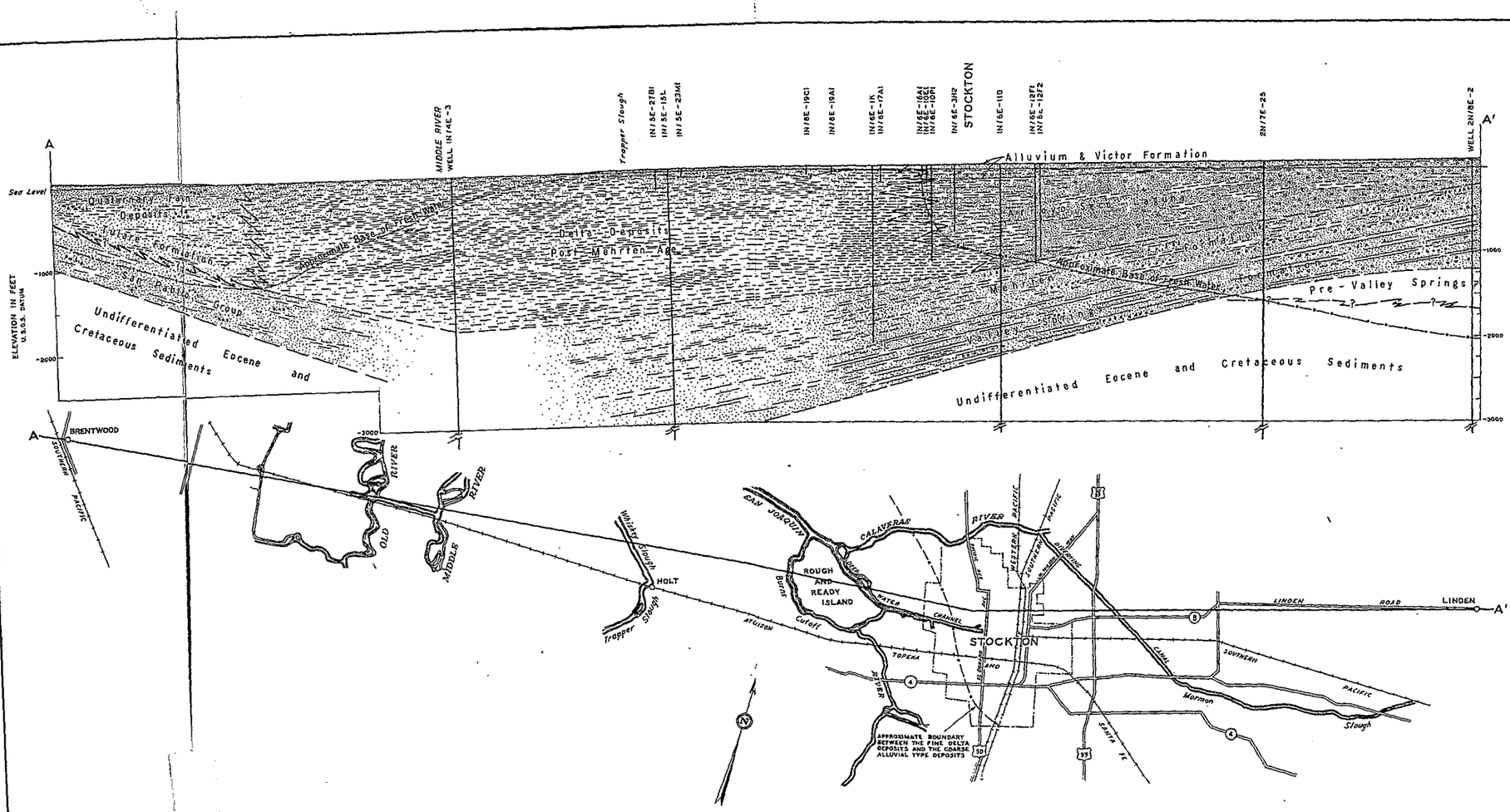
WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA

INVESTIGATION OF THE SACRAMENTO–SAN JOAQUIN DELTA

AREAL GEOLOGY
1956

SCALE OF MILES
0 1 2 3 4

PLATE 2



LEGEND

- CLAY
- SHALE
- SAND
- GRAVEL
- "LAVA"
- FORMATION BOUNDARY (APPROXIMATE)
- LINE BELOW WHICH CHLORIDES GENERALLY EXCEED APPROXIMATELY 300 PPM
- APPROXIMATE BOUNDARY BETWEEN THE FINE DELTA DEPOSITS AND THE COARSE ALLUVIAL TYPE DEPOSITS

GEOLOGIC AGE	FORMATION	DESCRIPTION
RECENT	ALLUVIUM	SAND, GRAVEL AND CLAY
PLEISTOCENE	VICTOR	SAND, SILT, GRAVEL AND CLAY
PLEISTOCENE	ARROYO SECO AND UNNAMED GRAVEL	SAND AND GRAVEL
PLIOCENE	LAGUNA	SAND, SILT, GRAVEL AND CLAY
PLIOCENE AND/OR MIOCENE	MEHRTEN	ANDESITIC AGGLOMERATE, SAND AND GRAVEL
MIOCENE	VALLEY SPRINGS	SAND, CLAY AND RHYOLITIC MATERIAL
MIOCENE	SAN PABLO GROUP	SANDSTONE AND SHALE
EOCENE AND CRETACEOUS	UNDIFFERENTIATED	MARINE SAND, CLAY AND SHALE

WATER PROJECT AUTHORITY
OF THE
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INVESTIGATION OF
THE SACRAMENTO-SAN JOAQUIN DELTA

GENERALIZED GEOLOGIC SECTION A-A'
1956

HORIZONTAL SCALE IN MILES
0 1 2 3

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GEOLOGIC SECTIONS B-B' AND C-C'

INVESTIGATION OF THE SACRAMENTO-SAN JOAQUIN DELTA

1956

WATER PROJECT AUTHORITY OF THE STATE OF CALIFORNIA

HORIZONTAL SCALE 2" = 1 MILE

ELEVATION IN FEET - U.S.C.G.S. DATUM

SEA LEVEL -100 -200 -300 -400

SECTION C-C'

C — BRENTWOOD — 1N/3E-18E1

25/5E-35F2
25/5E-35E1
25/5E-26G1
25/5E-24N1
25/5E-26L1
25/5E-22P1
25/5E-21J1
TRACY
25/5E-9Q1
25/5E-18D1

Tom Paine Slough
15/5E-32E1
FABIN TRACT
Grant Line Road
15/5E-28H1
Indian Slough
2N/3E-36M1
GRUPOO TRACT
2N/4E-31R1
15/5E-16M1
15/5E-15F1
15/5E-9Q1
15/5E-35F1
UNION ISLAND
Old River
1N/5E-34L1
15/4E-13D1
WOODWARD ISLAND
1N/5E-31N1
Middle River
Middle River
1N/6E-31L1
1N/5E-21G1
DRESCHER TRACT
1N/5E-16R1
Trapper Slough
1N/5E-20E1
1N/4E-24L1
UPPER JONES TRACT
1N/4E-22H1
1N/4E-15 EBMUD
1N/4E-17D1
LOWER JONES TRACT
1N/4E-3N1
1N/4E-3M1
2N/4E-31R1
Empire Cut
2N/4E-34M1
WILLOW ISLAND
Middle River
BACON ISLAND
2N/3E-26M1
Connection Slough
MANDEVILLE ISLAND
Middle River
2N/4E-10B
WEBB TRACT
2N/4E-5
SAN JOAQUIN RIVER
VENICE ISLAND
3N/4E-34D
3N/4E-13P1
Potato Slough
BOULDIN ISLAND
3N/4E-17Q
3N/4E-7
MOKELUMNE RIVER
TYLER ISLAND

SECTION B-B'

1N/5E-11K1
ROBERTS ISLAND
2N/5E-35M2
1N/5E-1Q1
SAN JOAQUIN RIVER
1N/6E-5M2
1N/6E-8K1
1N/6E-5J4
1N/8E-4P1
1N/6E-15E1
1N/6E-10P1
1N/6E-15H1
1N/6E-10R1
Mormon Slough
1N/6E-11C1
1N/6E-19H1
1N/6E-12F1
STOCKTON
C'

LEGEND

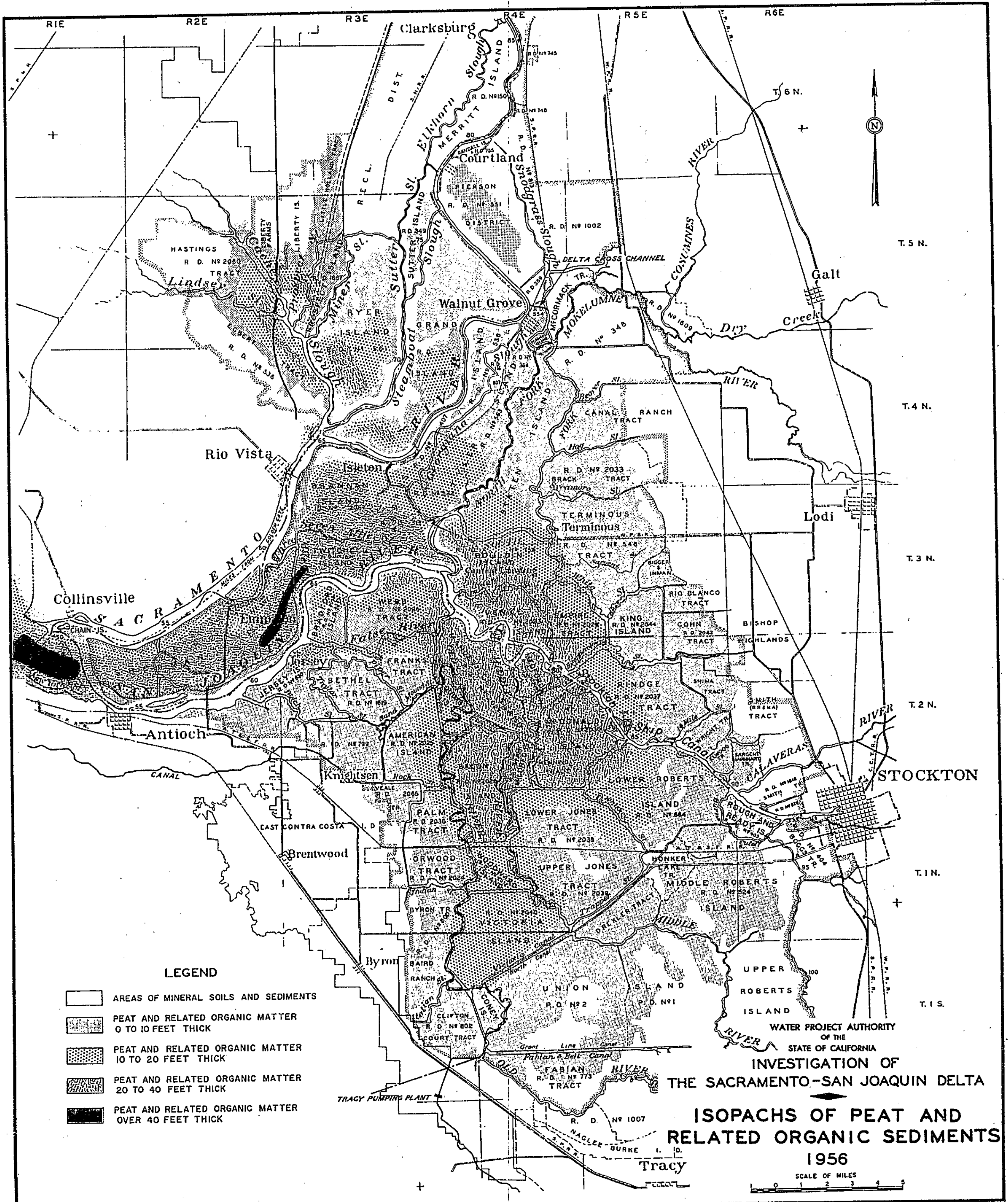
GRAVEL
GRAVEL AND SAND
GRAVEL AND CLAY
SAND
SAND AND CLAY
CLAY
PEAT AND RELATED ORGANIC SEDIMENTS
SPONTANEOUS POTENTIAL CURVE
RESISTIVITY CURVE
ELECTRIC LOG

ELEVATION IN FEET - U.S.C.G.S. DATUM

PLATE 3

C-111175

PLATE 4



C —111176

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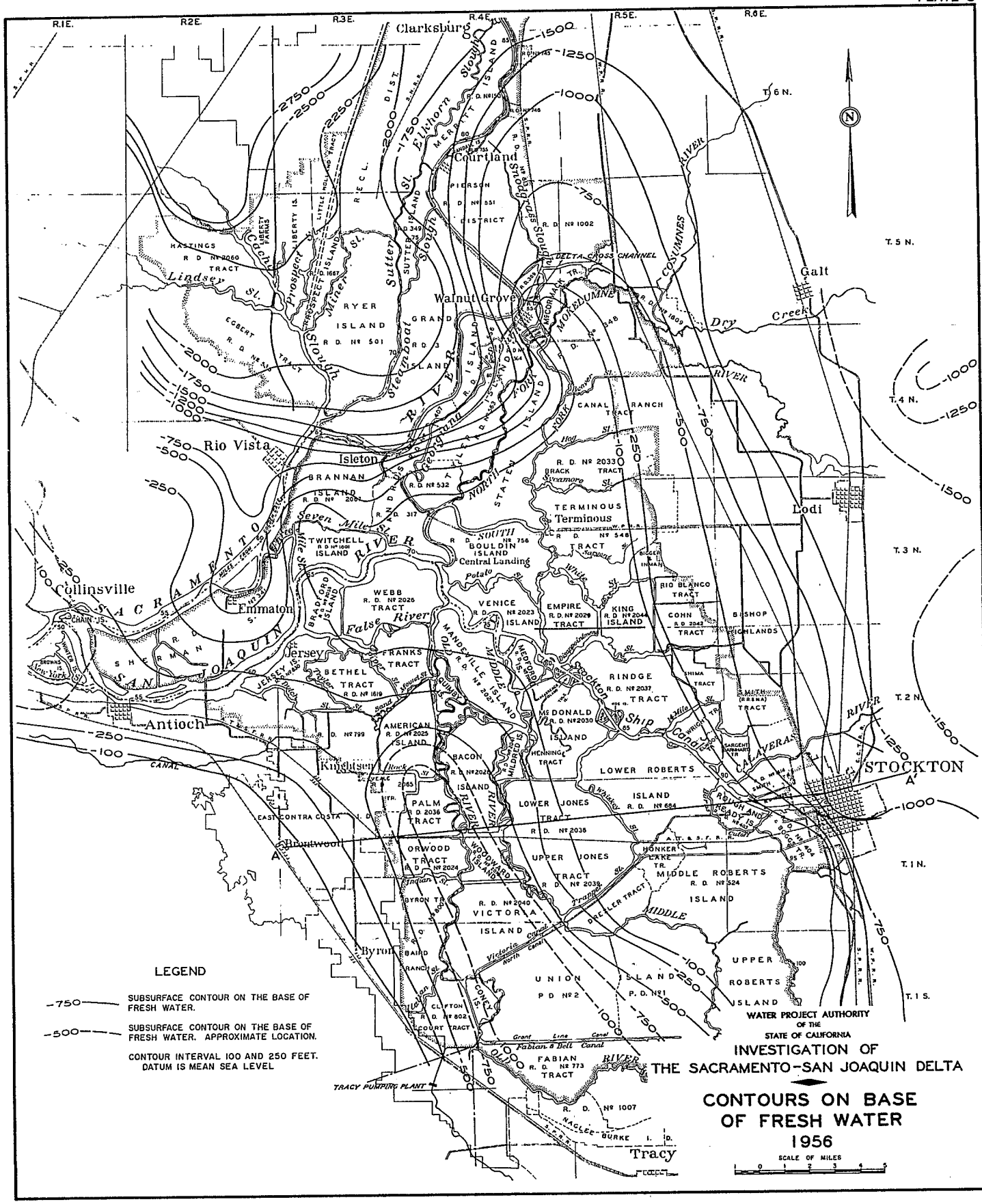
PLATE 5



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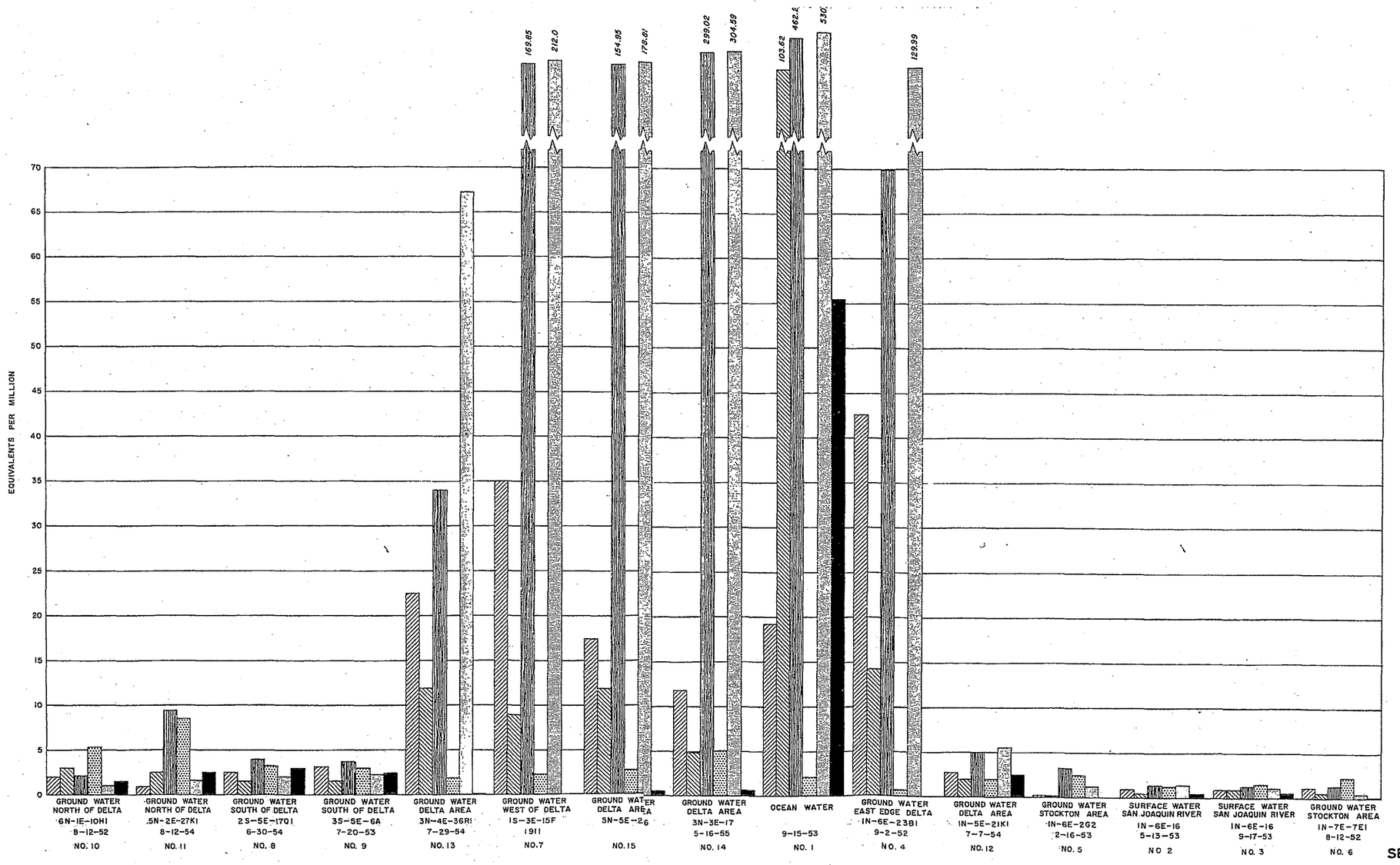


LEGEND

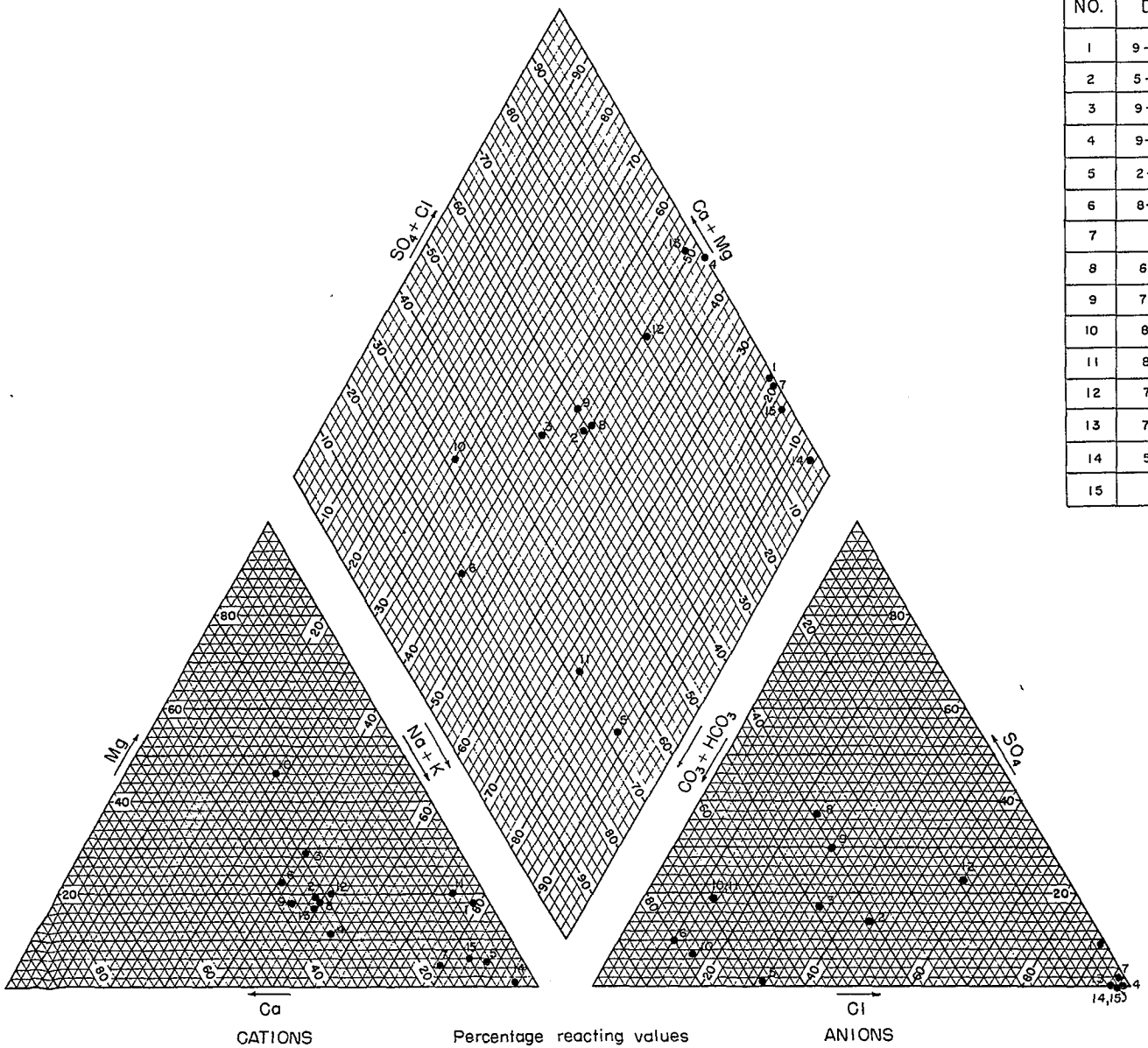
- CALCIUM
- MAGNESIUM
- SODIUM AND POTASSIUM
- CARBONATES AND BICARBONATES
- CHLORIDES
- NITRATES AND SULPHATES

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA

INVESTIGATION OF
THE SACRAMENTO-SAN JOAQUIN DELTA

COMPARATIVE MINERAL ANALYSES
OF
SELECTED SURFACE AND GROUND WATERS
1956

PROPERTIES



NO.	DATE	LOCATION	DEPTH IN FEET
1	9-15-53	OCEAN WATER OFF POINT CABRILLO	-
2	5-13-53	SAN JOAQUIN RIVER AT GARWOOD BRIDGE 1N-6E-16	-
3	9-17-53	SAN JOAQUIN RIVER AT GARWOOD BRIDGE 1N-6E-16	-
4	9-2-52	EAST EDGE OF DELTA 1N-6E-23B1	2000
5	2-16-53	STOCKTON AREA 1N-6E-2G2	1000
6	8-12-52	STOCKTON AREA 1N-7E-7E1	250
7	1911	WEST OF DELTA IN FOOTHILLS OF COAST RANGE 1S-3E-15F	10
8	6-30-54	SOUTH OF DELTA NEAR TRACY 2S-5E-17Q1	620
9	7-20-53	SOUTH OF DELTA NEAR TRACY 3S-5E-6A	170
10	8-12-52	NORTH OF DELTA, NORTHWEST OF RIO VISTA 6N-1E-10H1	150
11	8-12-54	NORTH OF DELTA, NORTHWEST OF RIO VISTA 5N-2E-27K1	55
12	7-7-54	DELTA, WEST OF STOCKTON 1N-5E-21K1	40
13	7-29-54	DELTA AREA 3N-4E-36R1	100±
14	5-16-55	DELTA AREA 3N-3E-17	5400
15	-	NORTHERN PART OF DELTA AREA 5N-5E-26	3300

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA

INVESTIGATION OF
THE SACRAMENTO-SAN JOAQUIN DELTA

WATER ANALYSIS DIAGRAM OF SELECTED SURFACE AND GROUND WATERS
1956

C-111179

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